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LORENTZ MICROSCOPY OBSERVATION OF MAGNETIC GRAINS IN Co-Sm // Cr FILMS

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Abstract: This paper presents our recent Lorentz microscopy study of magnetic domain structure and its relation to the nanostructure of Co-Sm films. The magnetic domains were imaged by Foucault Lorentz mode and the corresponding nanostructure was revealed by bright field and high resolution images. The nanostructure is composed of clusters of 20 nm grown on Cr grains. Each cluster is formed by the amorphous matrix and about 5 nm crystallites distributed in the matrix. It is found that each cluster forms a magnetic grain. Such magnetic grains show uniform contrast near the magnetic domain wall, and correspond to the switching volume in magnetic reversal. The magnetic grain (about 20 nm) is much larger than the size of the crystallites (5 nm) distributed in the amorphous matrix. It is the magnetic grain size that affects the noise response when the film is used as a high density recording medium.

I INTRODUCTION

Co-Sm films have been shown to be a promising candidate for future longitudinal recording media [1,2]. Recent microstructure characterization of Co-Sm films has shown that the microstructure is composed of the amorphous matrix and crystallites with a grain size of about 5 nm [3]. The Co-Sm films deposited on Cr underlayers form about 20 nm cluster structure on each Cr grain [4]. The crystal structure of the crystallites in Co-Sm was found to have the close-packed structure [5]. The anisotropy was explained by the $(\bar{1}100)$ $[0001]$ // Cr $(\bar{1}2\bar{1})$ $[\bar{1}01]$ epitaxy [6]. The switching volume for magnetization reversal was measured by the time dependence of magnetization of the film [7]. This paper presents our recent Lorentz microscopy study of magnetic domain structure and its relation to the nanostructure of the Co-Sm films.

II EXPERIMENTAL PROCEDURE

The Co-Sm target used for deposition has a nominal composition of $Co_{4.2}Sm$. The films were deposited by DC magnetron sputtering under an Ar pressure of 12 mTorr at room temperature. The film configuration from substrate to film is 220 μm glass, 80 nm Cr, 96 nm Co-Sm and 10 nm Cr. 3 millimeter plan view TEM samples were dimpled to 5 microns at the center and then ion milled until perforation. The Lorentz microscopy was performed using a JEOL 2010 transmission electron microscope operating at 200 kV.

III RESULTS AND DISCUSSION

In order to describe our result succinctly, we clarify the following terminology. A crystallite is identified by the similar lattice fringes observed in the HREM image. A cluster, which is grown on a single Cr grain, is composed of amorphous matrix in which about 5 nm crystallites are distributed. A magnetic grain (or switching volume) is the smallest volume which flip coherently in magnetization reversal. A magnetic domain, which could be composed of many magnetic grains, is a region in which magnetization is in one direction. Figure 1 is a Foucault mode Lorentz image of the domain structure in an as-deposited Co-Sm film. The domain size is from 50 nm to 200 nm. Figure 2 shows the detail of a domain consisting of many magnetic grains. Figure 2 (a) is a normal bright field TEM image in which little contrast is observed exempt the brightness change corresponding to the thickness change of the

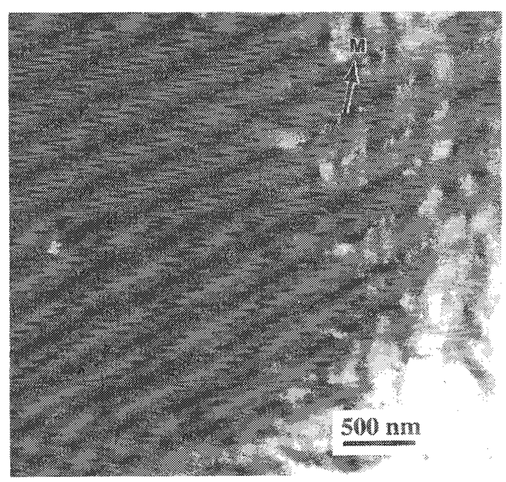

Figure 1 Magnetic domain structure in a Co-Sm film.

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specimen. Foucault mode Lorentz images reveal a half-moon shape domain with bright and dark contrasts as shown in Figure 2 (b) and (c), respectively. Further optical enlargement of Figure 2 (a), (b) and (c) reveals the cluster structure of about 20 nm in Figure 3 (a), (b) and (c). In Figure 3 (b) and (c) each cluster shows uniform contrast as indicated by the arrows, suggesting that the magnetization in each cluster is in one direction and forms a magnetic grain.

Figure 4 is a HREM image showing the detailed structure within a cluster. Each crystallite, which is about 3 to 5 nm, is recognized by the lattice fringes as indicated by a capital letter C. Each cluster is separated from the adjacent clusters by the gap (indicated by the letter G), inherited from the Cr underlayer. Such clusters are well revealed by TEM bright field imaging as shown in Figure 3 (a).

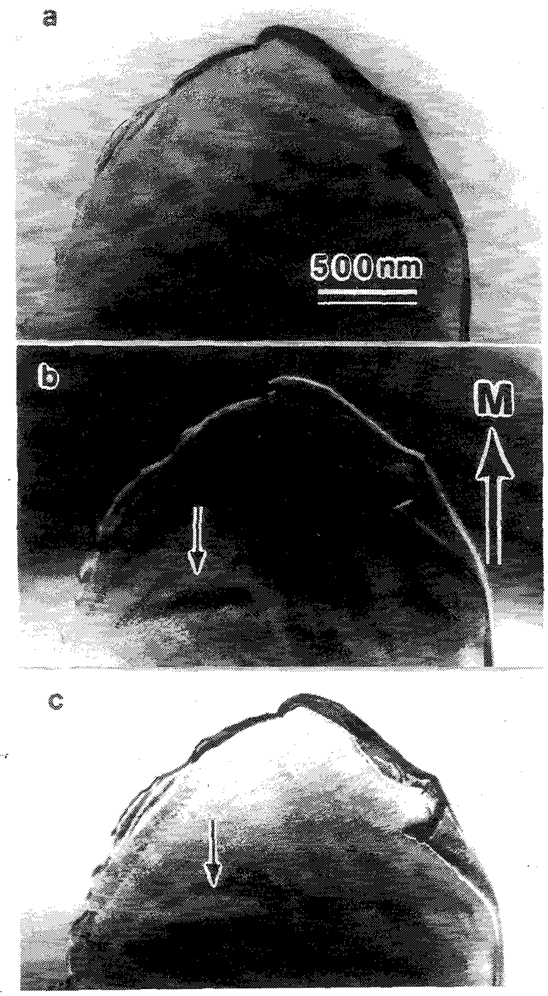

Figure 2. Cluster structure and a magnetic domain in the Co-Sm film. (a) is bright field image, (b), (c) are Lorentz images. A magnetic domain appearing dark at (b) and white at (c) is indicated by the arrows.

The switching volume V* was measured by the field-sweep rate $\frac{dHa}{dt}$ dependence of coercivity Hc according to the equation:

$$Hc = k + \frac{k_B T}{V^* M_s} \ln \frac{dHa}{dt} \qquad (1)$$

The magnetic grain size D was deduced from the switching volume assuming a cubic domain for 24 and 96 nm thick films. For 6 nm thick film, the D is deduced by $D=(V^*/6)^{1/2}$ for comparison. The result is listed in table 1.

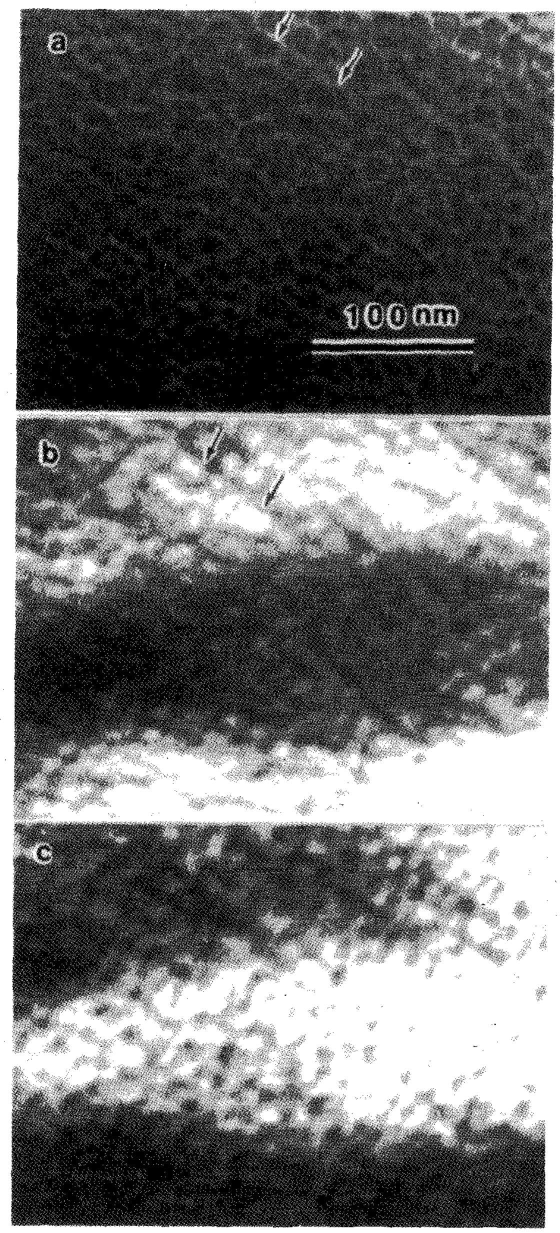

Figure 3 Enlarged images shown in Figure 2.

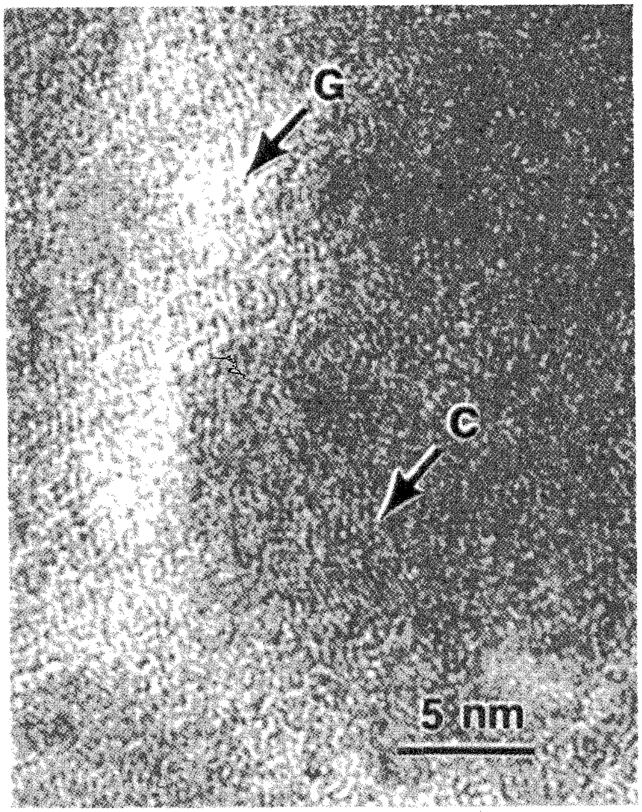

Figure 4. HREM image of a cluster grown on a Cr grain.

Table 1. Switching volume measurement of Co-Sm films.

thickness (nm)	V* (nm^3)	D (nm)	coercivity (kO)
6	2600	20	0.61
24	4500	17	2.58
96	12000	23	0.92

This result shows that the magnetic grain size observed by Lorentz microscopy is consistent with the switching volume measurement.

The important issue addressed in this paper is that the magnetic grain size is different from the physical grain size. It is the magnetic grain size, rather than the physical grain size, that should be used for noise estimation. For the current Co-Sm films, the magnetic grain size is about 20 nm while the crystallite size is about 5 nm. This suggests that the crystallites and the amorphous phase within a cluster are magnetically strongly coupled. The decoupling between adjacent clusters is promoted by the gaps inherited from the Cr underlayer. Assuming that 1000 magnetic grains are required in one bit to generate 30 db signal-to-noise ratio, the bit size is approximately $1000x20x20=4x10^5$ nm^2 for the Co-Sm film. This would lead to a maximum areal recording density of about 1.6 Gb/in^2.

IV CONCLUSION

In this Lorentz and high resolution transmission electron microscopy study we have shown that the magnetic grains and physical grains are different for Co-Sm films. A magnetic grain is formed by a cluster grown on a Cr grain and has the size of about 20 nm. The physical grains are embedded in the amorphous matrix and are about 5 nm in diameter. Switching volume measurement by magnetization reversal indicates the magnetic grain size is in the range of 17 to 23 nm, and is consistent with the Lorentz microscopy result.

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